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Steel Castings

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STEEL CASTINGS

BY

Charles Alva Washburn

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
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OF THE
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OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

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HISTORY

The use of iron can be traced to the earliest ages of antiquity. Copper and bronze may have been used at as early a period as iron, and for many centuries after their use began they undoubtedly superseded iron to a large extent, but the common theory that there was a copper or bronze age before iron was either known or used is discredited by Old Testament history, by the earlier as well as the later literature of the ancient Greeks, and by the discoveries of modern antiquarians.

Thotmes the First who is supposed to have reigned about seventeen centuries before Christ, is said in a long description at Karnak, to have received from the chiefs, tributary kings, or allied sovereigns of Lower Egypt, presents of silver and gold, "bars of wrought metal, and vessals of copper, and of bronze, and of iron". From the region of Memphis he received wine, iron, lead and other products. An expedition which the same king sent against Chadasha brought back among the spoils which it had taken "iron of the mountains, 40 cubes".

Belzoni found under the feet of one of the sphinxes at Karnak an iron sickle which is supposed to have been placed there at least six hundred years before Christ. In 1837 a piece of iron was taken from an inner joint of the great pyramid at Gizeh under circumstances which justify the theory that it is as old as the pyramid itself. The reference to iron in Deuteronomy, 4 - 20, apparently indicates that in the time of Moses the Egyptians were engaged in its manufacture, and that the Isralites were at least

as familiar with the art as their taskmasters. "But the Lord hath taken you and brought you forth out of the iron furnace, even out of Egypt". A small piece of very pure iron was found under the obelisk which was removed from Alexandria to New York in 1880 by Commander H. H. Zorringe, of the United States Navy. This obelisk was erected by Thotmes the Third at Heliopolis about 1600 years before Christ, and removed to Alexandria about twenty-two years before the Christian era. The iron found under it was at least 1900 years old.

Diamachus, a writer who was contemporary with Alexander, enumerates four different kinds of steel and their uses,- the Chalybdic, Synopic, Lydian, and Lacedaemonian. Each kind of steel was adapted to the manufacture of particular tools. From the Chalybdic and Synopic were made ordinary tools; from the Lacedaemonian were made files, augers, chisels, and stone cutting implements; and from the Lydian were made swords, razors, and surgical implements. The accounts left by this writer and by other writers indicate great proficiency in the use of steel by the Greeks, and the possession by them of much skill in its manufacture.

Toledo has been famous since the Roman occupation of Spain for its manufacture of steel swords, but this industry existed at Toledo before the appearance of the Romans. A certain degree of mystery has always surrounded the manufacture of these swords, and the same may be said of the manufacture in ancient times of the equally celebrated Damascus blades.

From the first to eighth century of the Christian era the history of the manufacture of iron in European countries is great-

ly obscured, ard the processes which were in operation cannot be described. In Asia and Africa the art had previously received less and less attention through the gradual transfer of political power and of civilization to the northern shores of the Mediterranean. Greece, which had acquired much of this power, had in time surrendered her leadership to Rome, and in the fifth century after Christ Rome herself fell before the northern barbarians. Except in Spain where the Visigoths established a powerful empire in the fifth century, under which the arts of ancient civilization were encouraged, the iron industry is nowhere throughout Europe known to have flourished from the timewhen Rome commenced her final struggle with the northern invaders down to about the beginning of the eighth century. At this time we begin to hear of the iron industry taking a fresh start in many European countries, experiencing a revival. With this revival we hear authentically for the first time of the Wolf furnace, or "stuck-ofen", in Austria, Bohemia, Germany, Belgium, and other Continental countries. This furnace was higher than the old furnaces, and thus allowed a greater concentration of heat.

Overman says that Wolf furnaces, or bloomaries, of which there yet remain a few in Hungary and Spain, are generally from ten to sixteen feet high, two feet wide at top and bottom, and about five feet in widest place. The early Wolf furnaces were not more than ten feet high. An opening in front about two feet square called the breast, was kept open until the furnace was heated, when, coincidently with the closing of the breast with brick, the ore and charcoal were thrown into the furnace, and the blast applied from "at least two bellows and nozzles, both on the

same side". The product was a mass of mixed iron and steel, which was taken out of the breast and reduced under the tilt hammer to blooms, and under smaller hammers to bars and other forms. The annual production of a Wolf furnace was from one hundred to one hundred fifty tons. Overman further says : "By this method good iron as well as steel is always furnished; in fact the product consists of a mixture of iron and steel; of the latter skillful workmen may save a considerable amount. The blooms were a mixture of fibrous iron, steel and cast iron. The latter flows into the bottom of the forge fire, in which the blooms are reheated, and is then converted into bar iron by the same method that is used to convert common pig iron. If the steel is not sufficiently separated it is worked along with the iron." At Solling, in Carinthia, a Wolf furnace was built in 1775 which was provided with two common bellows worked by water wheels, each bellows being eight feet long and three and three-quarter feet wide.

Percy says: "The transition from the old bloomary to the modern blast furnace was very gradual, and the "stuck-ofen" is the final development of the furnaces in which iron in the malleable state was produced direct from the ore."

The Pyrenean Forge shown in the following sketch essentially consisted of silicious stone bottom, covered over with a "basque" of powdered charcoal rammed down, with a tuyere inclined down as shown in figure. The front part of the forge was filled up with the ore to be reduced and the back part with charcoal, and the whole coated over with a moist layer of mixed fine ore and charcoal dust to moderate the combustion.

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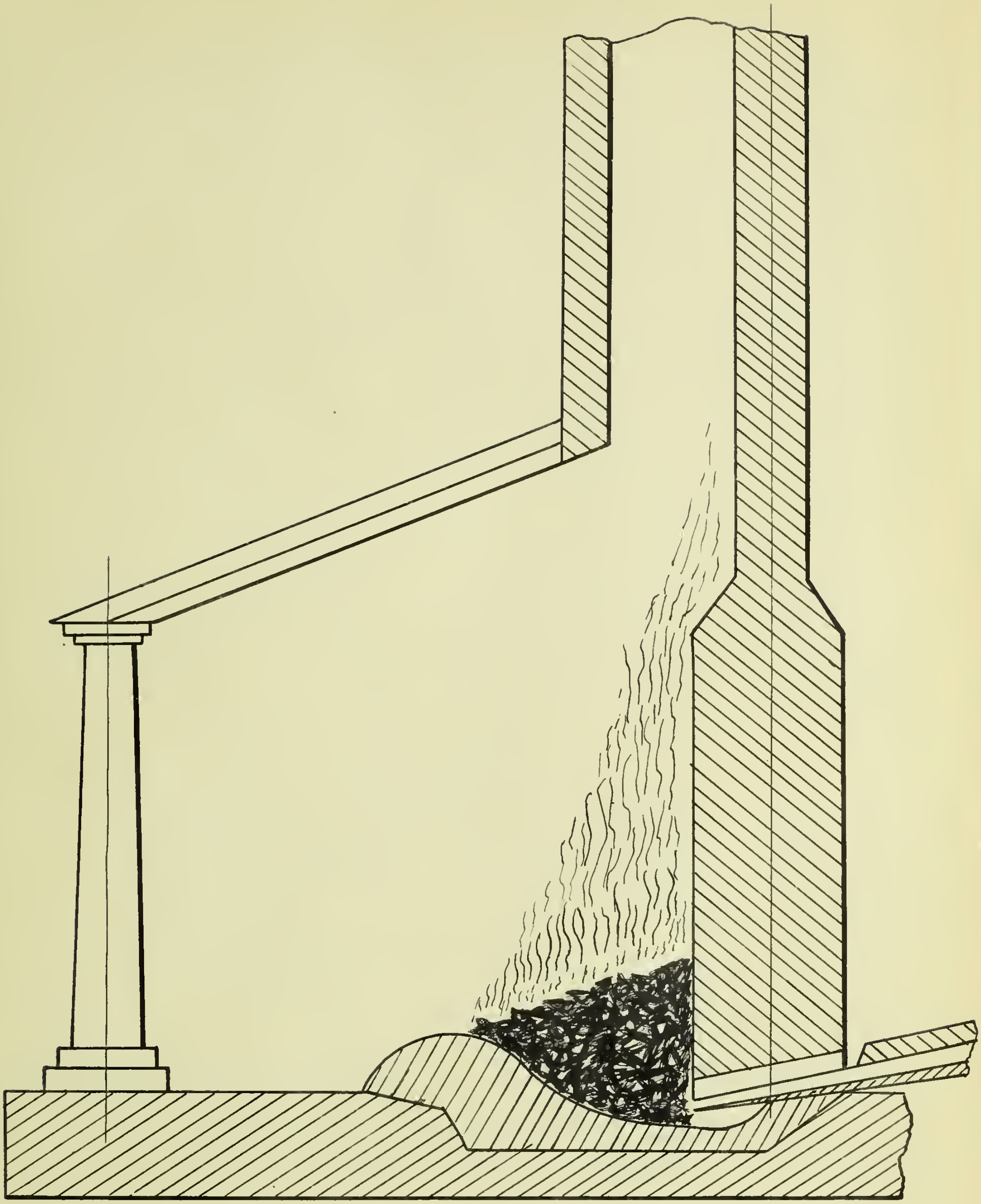


PYRENEAN FORGE.

No. 1

The methods of producing steel which were in use before Huntsman succeeded in making crucible steel at Sheffied in 1740, were substantially only three in number. The first method was either closely allied to, or was wholly identical with the direct or Catalan process for producing iron, the product being variously known as natural steel, raw steel, or German steel. The second method was the Indian process for converting small pieces of bar iron into steel in crucibles, the product being wooty, or Indian steel. The third process was the cementation process, in which bars of the best iron were carbonized by being heated in contact with charcoal, the result being blister steel, or shear steel.

The celebrated steel works of Freidrich Krupp, at Essen in Germany, were founded in 1815 by Freidrich Nicolai and Krupp, for the purpose of making cast steel. The works are now in control of a great grand daughter of the founder.

Steel was largely made in England as early as 1609, and most probably in cementation furnaces, the product being known as blister steel and shear steel. In the year mentioned John Hawes held the sight of the Abbey of Robertsbridge in Sussex, upon which were eight steel "furnaces". The invention of crucible cast steel originated with Benjamin Huntsman, an English clockmaker at Sheffield in 1740, and not only Sheffield, the principle seat of its manufacture, but all England as well has greatly profited by his discovery. The manufacture of cemented steel also became a leading industry of Sheffield in the eighteenth century.

The whole world is indebted to England and Scotland for the inventions which gave a fresh impetus to the manufacture of iron in the eighteenth century. Payne and Hanbury, who first succeeded

in rolling sheet iron; Darby, who first successfully and continuously used coke in the blast furnace; Huntsman, who invented the process of making steel in crucibles; Smeaton, 1724-1792, who invented cast iron blowing cylinders; and Cort, who invented Grooved rolls and the puddling furnace, were Englishmen, while Watt, 1779- who perfected the steam engine was a Scotchman. Bessemer the Englishman invented in 1855 the process which bears his name and is the flower of all metallurgical achievements - a share in the honor of this invention, however, being fairly due to the co-operating genius of Robert F. Mushet, also an Englishman but born of Scotch parentage. The Siemens regenerative gas furnace which has been so extensively used in the manufacture of iron and steel, is also an English invention.

Although iron ore in this country was first discovered in North Carolina, and the manufacture of iron was first undertaken in Virginia, the first successful iron works were established in the province of Massachusetts Bay. In 1632 mention is made by Morton of the existence of "iron stone" in New England, and in November, 1637, the general court of Massachusetts granted to Abraham Shaw one-half of the benefit of any "coles or yron stone wch. is in the countryes disposeing". Iron ores had been discovered in the flat meadows on the upper parts of the Saugus River, near Lynn, soon after its settlement in 1629, and in 1642 specimens were taken to London by Robert Bridges in the hope that a company might be formed for the manufacture of iron. This hope was soon realized in the formation of "The Company of Undertakers for the Iron Works", consisting of eleven English gentlemen, who advanced one thousand pounds to establish the works. John Winthrop Jr.

had previously gone to England, and he appears to have assisted Mr. Bridges in securing the organization of the company, becoming a member of the company as did others among the colonists. A foundry was erected on the western bank of the Sangus River. The workmen were brought from England by John Winthrop, Jr. This foundry at Lynn says Lewis "was the first which was established in America".

In 1644, as stated by Lewis, the general court granted many special privileges to the company. On March 7, 1644, it was granted three miles square of land at each of six places it might occupy in the prosecution of its business. On May 14, 1648, the general court passed an order declaring that "ye iron worke is very successful (both in ye richness of ye ore and ye goodness of ye iron)" and that between twelve hundred pounds and fifteen hundred pounds had already been disbursed "with which ye furnace is built, with that which belongeth to it, --- and some tuns of sowe iron cast in readiness for ye forge ---. There will be neede of some fifteen hundred pounds to finish ye forge." On May 6, 1646, Richard Leader, the general agent of the company, purchased "some of the country's gunnes to melt over at the foundery". At this time the output of the works was about seven tons per week. After 1671 the works were operated fitfully, and about 1688 they appear to have been finally abandoned.

The enterprise at Lynn embraced a blast furnace, or "Foundery", and a refinery forge. The term foundery was long used as synonym for furnace, castings being made directly from the furnace.

Joseph Jenks was a machinist at the Lynn works who had come from England and was a man of much skill and inventive genius.

He prepared the moulds for the first castings that were made at Lynn. "A small iron pot, capable of containing about one quart," was the first article cast at the furnace. It is said that the pot is heavy enough to make three in the hands of a modern moulder.

The works at Lynn were followed by numerous ones of similar characteristics. For a hundred years after its settlement in 1620 Massachusetts was the chief seat of the iron manufacture on this continent. Most of its iron enterprises during this hundred years were ore bloomaries, but there were blast furnaces also, although the latter as a rule produced only hollow-ware and other castings and not pig iron. Iron does not appear to have been made within the limits of Maine, New Hampshire, or Vermont until the eighteenth century.

About 1722 a bloomary forge was built at Bridgewater,which was active in 1750. In 1738 High Orr, a Scotchman, established at this place a gun factory, and about 1748 he made five hundred muskets for the Province of Massachusetts Bay, which are claimed to have been the first muskets made in this country. Subsequently he established a cast iron cannon foundry at Bridgewater. In 1730 iron works were erected at Plympton, now Carver, which appear to have included a blast furnace, as mention is made of "The first cast-iron tea-kettle" having been cast at Plympton between 1760 and 1765.

In 1731 there were officially reported to be in Massachusetts "several forges for making bar, and some furnaces for cast iron or hollow-ware, and one slitting mill, and a manufacture for nails".

The development of the rich brown hematite iron ores of Western Massachusetts commenced about 1750. It is said, however, that as early as 1731 iron ore was taken on horseback in leather bags to Ousatonic, now Great Barrington, in Berkshire County, from Old Hill mine, in Litchfield County in Conneticut, a distance of sixteen miles and worked in bloomary forges. A furnace was built at Lenox, in Berkshire County, in 1765, and it made pig iron in the following year. It had an exceptionally high stack for that day - twenty-eight feet high, and was blown with tuyeres. This furnace was torn down in 1881. In 1804 there were ten blast furnaces in Plymouth County, all producing castings exclusively. In 1804 Dr. James Thacher wrote a description of one of these furnaces, which he claimed to be the most valuable furnace with which he was acquainted. The furnace was built of stone, as were all other Plymouth furnaces. It was twenty feet high and twenty-four feet square, its walls being seven feet thick and its interior ten feet in diameter. Charcoal was the only fuel used and marine shells formed the only fluxing material. The furnace was lined with "fire stone" composed of "soft slate". A brick funnel at the top of the stack served to convey off the blaze and smoke. In an arch on one side there was a small aperture for the insertion of the pipes of two large bellows twenty-two feet long and four feet wide, which were kept in constant alternate motion by a water wheel twenty-five feet in diameter.

In 1750 it was officially reported that there was then in Massachusetts "one furnace for making steel", but its location is not given. The first steel works of which circumstantial information can be obtained were established at Easton, in 1775 or 1776

by Eliphalet Leonard. The steel produced by this plant was blister steel. In a letter written by Mr. Leonard he makes a statement concerning the manufacture of steel "from the pig, after the German manner", which is very important, it shows that this method of making steel was in use in this country in the last century, side by side, with the manufacture of blister steel - a fact not generally known at the present time.

Steel was manufactured in a small way in several of the American Colonies, either "in the German manner" or by the cementation process. Bishop states that the first suggestion of the manufacture of steel was made in 1655. At this time the manufacture of blister steel was a great mystery. Crucible steel had not then been invented.

In 1818 John and Jacob Rodgers, and a few others were engaged in the manufacture of saws at Valley Forge. Mr. Wood was the manager of the works. The company built a furnace in that year for the manufacture of crucible steel for saw plates, John Parkins and his son, both from England, being employed as practical steel makers. These persons are said to have made an unsuccessful attempt to make cast steel at New York City in 1812. The company at Valley Forge is said to have made some excellent steel, but the project was soon abandoned. Clay for crucibles was brought from Perth Amboy, and some plumbago crucibles were inported from England. This it is claimed was the first important crucible steel enterprise in our history. Prior to 1831 the best qualities of crucible cast steel used in this country were imported from Europe.

Cast steel which at first was made only from blister steel, was not made in the United States. Several attempts to make it

with profit had been failures. "The causes of failure", says the report, "were first the want of the best quality of blister steel; at a reasonable price, and second, the want, or expense, of crucibles of proper quality, wherein the blister steel is to be meltted. Black lead and a variety of clays have been tried, but the weakness of these materials has heretofore caused a loss to the manufacturer." In the first edition of Appleton's Cyclopeodia, printed in 1860, it was stated that "American cast steel is hardly known in the markets". During the period from 1831 to 1860 there was one notable and successful attempt to make steel of the best quality.

In August, 1832, William and John Hill Garrard, commenced the manufacture of crucible steel at Cincinnati, in works which had been previously erected by them. The works embraced a furnace for converting bar iron into blister steel; two pot-holes, each accomodating two pots or curcibles; and the necessary machinery for manufacturing saws and files. In August, 1832, the first cast steel was made, and in November of the same year, the first mill and cross-cut saws were made. In this plant Swedes' iron and considerable Missouri charcoal iron was used for the best cast steel; and for steel used for saws, springs, etc. Tennessee charcoal iron was used.

In the Cincinnati Directory for 1834, there will be found the following announcement: "Steel Saw and File Factory, on Plumb Street, owned by Middleton, Garrard & Company, Manufacturers of all Kinds of Cast Steel, by steam power."

Between 1828 and 1830 Simeon Broadmeadow, an Englishman, and his son made blister steel, and about 1831 they made some cast

steel in pots of their own manufacture. Their attempt to make cast steel was a failure. The first slab of cast plow steel ever rolled in the United States was rolled by William Woods at the steel works of Jones & Onigg, in 1846, and shipped to John Deere, of Moline, Illinois.

In 1852 McKelvy & Plair, of Pittsburg, made cast steel of good, but not always of the best quality. It was, however, of a quality so creditable, and so uniformly superior to any that had previously been made at Pittsburg, that the firm may be regarded as the pioneer in the production of cast steel in large quantities in that city.

While these experiments in the manufacture of the best quality of steel were being made at Pittsburg, other localities were engaged in making similar experiments. By far the most important of these were made by the Adirondack Iron & Steel Company, whose works were at Jersey City, New Jersey. They were built in 1848 to make blister steel from charcoal pig iron made in New York, and also to make cast steel. An attempt to make cast steel by melting the blister steel in clay crucibles was a failure, but subsequently cast steel of good quality was made in black lead crucibles. This result was reached as early as February, 1849. Of the excellent quality of the cast steel manufactured at this time, at these works there is abundant evidence in the testimony of government experts and also of many consumers. Its manufacture was continued until 1853, when the business was abandoned by the company. It had not proved to be profitable, partly because of the prejudice existing against American Cast Steel.

The manufacture in this country of crucible cast steel of the

best grades may be said to have been established on a firm basis after Hussey, Wells & Company; Park, Brother & Company; and Gregory & Company: in the years 1860, 1862, and 1863, respectively, succeeded in making it of uniform quality as a regular product. The event is one of great importance, as it marked the establishment in this country of a new industry which was destined to assume large proportions and to be of very great value. It met a want that had long been felt, and dissipated the long standing belief that this country possessed neither the iron nor the skill to produce good cast steel.

Sir Henry Bessemer, of London, the inventor of the process which bears his name, commenced in 1854 to experiment in the manufacture of iron for an improved gun. "In the course of his experiments", says Mr. J. S. Jeans in his work on Steel, "it dawned upon him that cast iron might be rendered malleable by the introduction of atmospheric air into the fluid metal". In 1855 and 1856 patents were granted to Mr. Bessemer for this discovery, but it was not until 1858 that complete success was achieved by him in the conversion of cast iron into cast steel.

The first Bessemer steel rails ever made in this country were rolled at the North Chicago Rolling Mill on the 24th of May, 1865, and the first ever rolled upon order, in the way of regular business were rolled by the Cambria Iron Company, of Johnstown, Pennsylvania, in August, 1867. In the early stages of the Bessemer Steel industry in this country great difficulty was experienced in obtaining suitable pig iron, and also materials for the lining of the converters. Our manufactures were uncertain whether American ores would make good Bessemer Pig iron, and many failures occurredin

using domestic pig iron that was unsuited for conversion into good steel. All difficulties, however, have been long overcome. It is now universally admitted that in the United States this industry has been brought to a higher state of perfection than in any other country.

The open-hearth process for the manufacture of steel, of which the Siemens-Martin furnace is the most popular type, consists in melting pig iron in a large dish shaped vessel, or reverberatory furnace, and afterwards decarburizing it by adding wrought iron, steel scrap, or iron ore, a deficiency of carbon being supplied as in the Bessemer Process, by the application of spiegleisen or ferro-manganese. The product is steel containing any amount of carbon that may be desired. The materials used are melted by the union in the furnace of atmospheric air and combustible gases, affording an intense heat. All of the heat employed is obtained by the use of a regenerative gas furnace.

The open-hearth process, although capable of producing as large masses of steel as the Bessemer process, is much slower in its operation, but it possesses the advantage over its rival that the melted mixture may be indefinitely kept in a state of fusion until experiments with small portions determine the exact conditions necessary to produce a required quality of steel.

As early as 1861 Dr. Siemens experimented with the regenerative furnace in the production of cast steel in a reverberatory furnace or open-hearth, for which application of the furnace he secured a patent. In 1864 Messrs. Emile & Martin erected a Siemens furnace of their own construction. In this furnace they produced cast steel of a good quality, and were awarded a gold medal

at the Paris Exposition in 1867, for their product.

The great progress made by the World's Iron and Steel Industries in the last hundred years is as plainly marked in the improvements of the processes of manufacture as in the increased demand for iron and steel products. Nearly all the blast furnaces of a hundred years ago were blown with leather or wooden bellows by water power, and the fuel used was chiefly charcoal. We can not fully comprehend the marvelous nature of the changes which have taken place in the iron and steel industries of this country in recent years, unless we compare the early history of those industries with their present development.

KINDS AND DEFINITIONS

Steel for castings is now made by the three following processes or modifications of them: (1) The Open Hearth Process; (2) The Crucible Process; (3) The Bessemer Process.

The Open Hearth Process is particularly suited for the manufacture of large castings, owing to the comparitive cheapness and uniformity of the melted metal. In making small castings of thin section, it is essential that the metal be very hot and fluid as it is poured into the mould, since molten steel cools with great rapidity, and will otherwise not completely fill the mold. It is commercially impracticable to make small castings from Open Hearth steel on account of the large amount of metal which would be lost by skulls in the ladles and by bad castings. Moreover. as ordinarily operated, the capacity of the furnace ranges from eight tons upward, and this must all be tapped at one time. These facts

necessitate having the pouring floor set with molds to the capacity of the heat and thus in the manufacture of small castings a very large pouring floor is required.

Small castings are made very satisfactorily from Crucible Steel. The objections raised to this process, are, its high cost of operation and the large equipment required in proportion to the tonnage of material manufactured.

The Bessemer Process recommends itself for a number of reasons as an acceptable method for producing steel for small castings. Presuming that a sufficiently hot and quiet steel of the proper quality can be obtained, one of the greatest advantages it offers is the elasticity in the quantity of its product. With a converter of two tons capacity the output may be governed by the fluctuations in orders, or by the capacity of the molding and pouring floors. The Open Hearth process to be worked economically, must be run day and night in order to avoid the loss in gas and labor entailed in keeping the furnace hot while idle. But with the converter process the sources of expense are stopped when the pouring is finished.

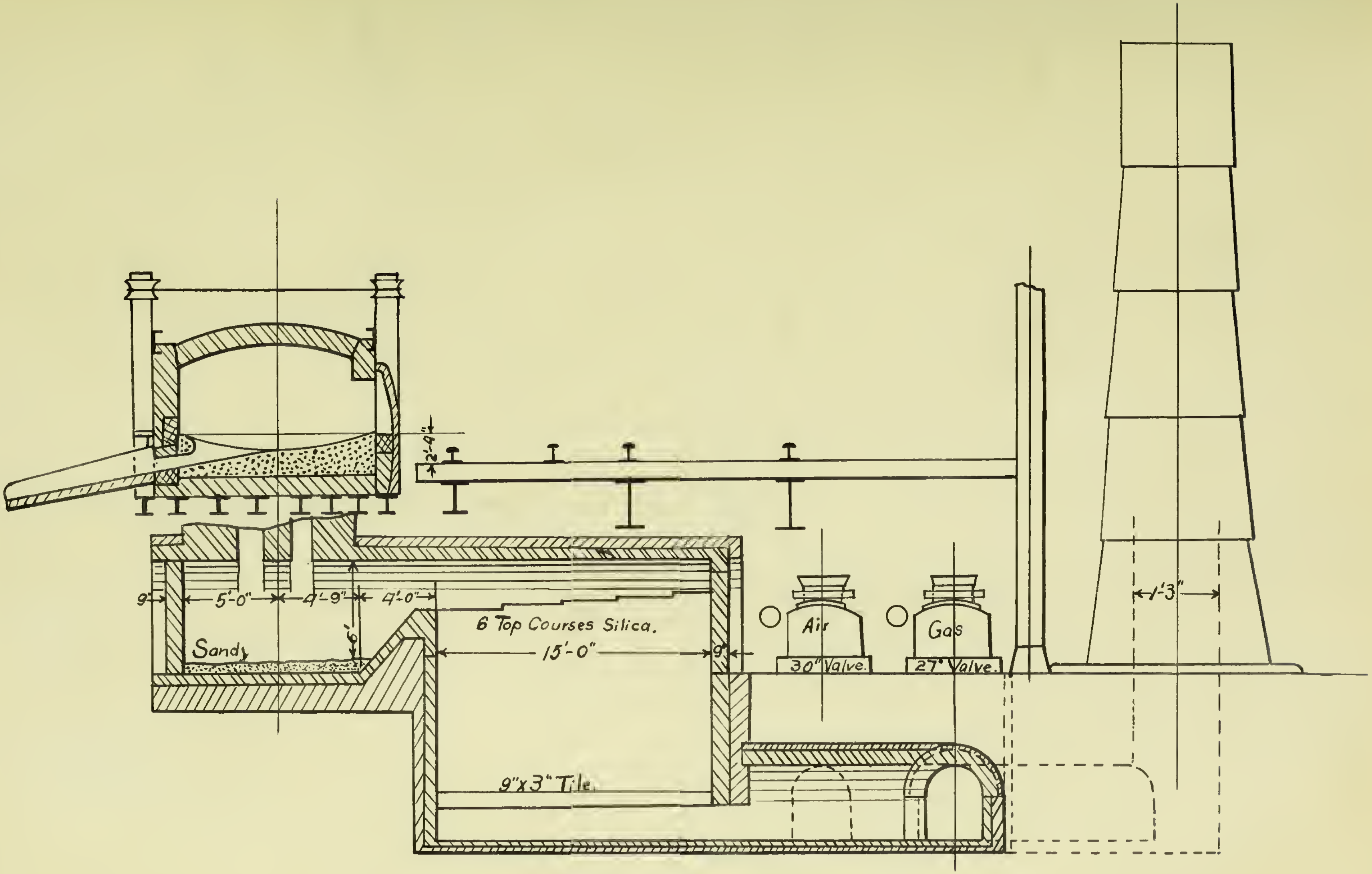
In order to obtain sufficiently hot steel by the Bessemer process, a number of modifications have been made in the original process, by variations in the method or place of introducing the blast. The best known of these methods are the Robert, the Walrand-Legenisel, and the Tropenas processes, named after their inventors.

USES - A great development has taken place, within the past few years, in the application of steel castings to machine

construction in lieu of forgings or castings of other metals. This has been due to a number of valuable characteristics of steel castings, which make their use suitable to a large variety of work. Chief among these features is the ability to obtain a metal of high tensile strength and ductility, in shapes difficult or impracticable to forge and at a price in most cases lower than that of a forging. Machine parts formerly made in cast or wrought iron can be considerably reduced in weight by the substitution of steel. This fact has been appreciated by the railroad companies in particular, as applied to locomotive and car designs. As an instance of this a reduction in weight of about four tons has been made on a passenger locomotive by the substitution of steel castings for forgings and iron castings. Steel castings can also be made of high magnetic permeability, and have therefore been largely adopted by manufacturers of electrical machinery.

OPEN HEARTH PROCESS

In American practice when large tonnages in output are sought, the Open Hearth Process is generally employed. Such furnaces working on Castings have a capacity of about twenty tons. This capacity approaches the limit that can be handled in jobing shops and will represent the general rule. Larger tonnages may be needed if the product is heavy work requiring but few moulds to receive a heat, and requiring but a short time to pour them, but in cases of a heat to be poured into a large number of moulds the time may be so extended that the metal will lose its temperature and there will be losses due to cold steel. The sketch number two shows the



2'-4"
9"
5'-0"
4'-9"
4'-0"
6"
Sandy
6 Top Courses Silica.
15'-0"
9"
9"x3" Tile.
Air
30" Valve.
Gas
27" Valve.
1'-3"

OPEN HEARTH STEEL FURNACE.

STATIONARY TYPE. No. 2

usual lines of a modern furnace of twenty tons capacity. Sketch number three shows it arranged for burning oil. These may be subjected to minor changes due to necessities arising from local conditions in erecting. The principles of construction are the same in both acid and basic furnaces, differences occurring in the character of the materials forming the hearth linings. Generally the furnaces are of the stationary type. In some plants will be found furnaces of the rolling or tilting type, each having some good points in its favor. The stationary type is cheaper of construction, not requiring the costly mechanical appliances essential to the other type. A strong argument in favor of the rolling type is the ability to drain the hearth at the end of a heat, thus emptying any pools that may form in the bottom due to excessive scarification and the ease with which they can be readily repaired with the proper refractories.

In stationary furnaces much time is lost, with much discomfort to the workmen, in emptying pools by means of scrapers. Another argument in favor of the tilting furnace is that the tapping hole troubles are eliminated. In stationary furnaces delays are encountered through "hard taps" as a result of the material used to close the tapping hole becoming fused.

CONSTRUCTION - The metal work, such as buck stays, tie rods, hearth pans, doors, etc., should be of rigid construction to withstand the heavy duty due to expansion of the brick work when the furnace is at working heat. All walls should be bound at the ends, and stiff rolled bars used wherever possible. In the regenerator chamber the ends of all outside or partition walls

should be bound, because the expansion may cause leaks and permit ignition of the gas before it reaches the body of the furnace. The subsoil at site of location is a very important item, as the foundation should be of rigid and first class masonry to guard against irregular settling. It should be of hard red brick laid in concrete. No part of the furnace structure should extend below the point at which water may be found.

Reversing valves should be of such construction that leakages and loss of gas will not occur when operated. The water sealed valve has the advantage over others. The stack should be of such construction as to induce a good draught and regulated by a damper.

Whenever possible the doors, door frames, and furnace fronts should be water cooled, making it more comfortable for the operator, and resulting in longer life for such parts. This arrangement is only possible in the stationary type of furnace. All gas producer flues should be roomy and if possible aboveground to allow ready access for cleaning out soot and tar.

The hearth length should be as great as possible in order that the full calorific value of fuel may be utilized as much as possible. Practical experience has taught that a twenty ton furnace can be safely operated with a hearth length of twenty to twenty-five feet, and a width of nine to eleven feet. The total area should be about nine square feet per ton of capacity. Generally the length will be two to two and one-half times the width. The depth of the fully lined hearth will depend upon the length and width. A shallow bath will give rapid working, but at the sacrifice of much burnt metal, or an excessive decrease in yield over metal charged. A deep bath will retard the melting and pre-

sent difficulties in maintaining desirable thermal conditions. The ranges for the proper depth will be between fifteen to twenty inches.

The efficiency of a regenerator chamber depends upon the number of"checkers" it can carry, and the direction of incoming and outgoing gaseous bodies. Here the direction means in a horizontal or vertical travel. In American practice the longest dimension of the chambers is horizontal, while in European practice some are built with greater depth than length. The purpose of the regenerator chambers is to store in them heat carried over by waste gases from the furnace body, the heat being absorbed by a large number of number one fire brick, so piled that the gases will have to pass through innumerable ducts. When the bricks are piled in this way they are called checkers. They should form rectangular passages of about three to three and one-half inches in width, running both horizontally and vertically. They should be piled in such a way that the passages will be zig-zag or "staggered". Generally they are staggered in a vertical direction with straight passages horizontally.

The question of draught has to be considered and with as many bricks as it may be possible to checker and with the greatest possible depth of chamber, the free working of the furnace will be augmented by straight passages in both directions. Indications as to heat absorption by the checkers can be gauged by temperature of waste gases entering stack with furnace at working heat.

Pyrometrical observations have been made showing the normal working conditions of the stack to be an average of five hundred degrees centigrade with gases entering outgoing down-takes at

fourteen hundred degrees centigrade. and with air at atmospheric temperatures entering chambers and passing through them in uptakes at one thousand degrees centigrade. This illustrates very well the absorption and radiating effect of checkers.

The flow of gases through the furnace is reversed in direction at intervals of about fifteen minutes, so as to utilize the heat absorbed in the checkers on side of furnace opposite to that at which gases enter before reversal. It would be possible to melt the best refractory lining by reaching high ranges of temperature by the principle of regeneration, but by careful watching on the part of the operator, flame and air volumes are properly regulated to prevent burning of the furnace. Without the system of regeneration it would not be possible to handle two hundred tons or less of liquid steel at a time in a single operation of an open hearth furnace.

ACID FURNACE BRICK WORK - Wherever the furnace body is subjected to uniform, high temperature, it is lined with high grade silica bricks. The piers and outside walls can be constructed of red brick, and the linings of flues and chambers including checkers are made of the best quality of fire brick. Silica brick can not be used for checkers because they will crumble under the varying ranges of temperature.

The hearth pan is lined with fire brick to the depth of nine inches or more, but above metal line silica bricks are used for the sides, and roof. With the brick work complete the furnace is dried moderately with a wood, or soft coal fire.

The gas or oil can then be turned on slightly at first and

then raised gradually to nearly full working temperature. Layers of silica sand are then spread over the bottom. They are put in in succession and between each interval the flame is allowed to set the sand until hard. This is repeated until the hearth lining will have reached the depth of eighteen to twenty inches, including the fire brick. Under skillful handling an acid furnace ought to turn out between nine hundred and one thousand heats per campaign at the rate of three heats per day.

BASIC FURNACE BRICK WORK:- With the exception of furnace body in regard to brickwork,the construction is the same as an acid furnace. The hearth pan is first lined with fire brick followed with magnesite bricks. Usually the bottom is lined with ground magnesite. It may be mixed with about five percent of anyhdrous tan and rammed in to form the hearth, and then slowly brought to full temperature, or the magnesite may be put in in the same way as sand in the acid process. Where the magnesite bricks meet the silica bricks of the walls, a parting of chromeore is placed as a neutral separation of the two to prevent fluxing,which is liable to ensue between them at working temperature. A Basic furnace ought to yield four hundred or more heats in a campaign.

Open Hearth furnace,number two, of the Solid Steel Casting Company, Chester, Pennsylvania, some time ago completed four hundred ninety consecutive heats with out any stop for repairs. During this campaign some 12,250,000 pounds of steel castings were made. The furnace is of the Herrick design, fifteen tons capacity, and is supplied with two improved gas producers.

It is difficult to make an actual comparison between oil and coal gas for steel melting on the basis of the cost per ton of metal produced. In certain localities. the figures may be in favor of coal, and in others in favor of oil. Yet the advantages of oil over coal in working results are so pronounced that discrepancies in cost against oil are offset by its usefulness. The oil is also useful for drying ladles, firing annealers, and core ovens.

MATERIALS FOR ACID PRACTICE.

MELTING STOCK - The composition of materials for acid castings comes within well defined limits, for the reason that the process is nearer a melting, rather than a refining one, owing to the fact that the metalloids. sulphur and phosphorus, are not removed during the conversion of the charge. The distinction between acid and basic melting stock exists only in the quantities of Sulphur and Phosphorus.

Pig Iron for ordinary practice analyses as follows:-

Total Carbon	2 - 3.5	percent
Silicon	.50 - 1.5	"
Sulphur	.04	or less
Phosphorus	.04	"
Manganese	.50 - .75	Percent

In addition to pig iron, steel scrap is bought on analysis. This is the product of rolling mills, etc., following basic practice, the amounts of sulphur and phosphorus are usually low, and they are the only elements of composition taken into account. A

representative analysis of steel scrap for acid practice is as follows:-

Sulphur	.015 - .03 percent
Phosphorus	.010 - .03 "

REFRACTORY LININGS - Silica sand forming the furnace hearth, being known as an acid, distinguishes between the two processes. It does not remove sulphur and phosphorus, the same amount of these elements being found in the finished product as when charged. The function of the silica sand is a refractory one. It must, however, set sufficiently to preserve the contour of the shallow dish-like formation of the hearth. This set or ~~sinter~~ must just be sufficient to resist abrasion due to the charging of stock.

FUEL - It is a question of local conditions as to whether the fuel may be natural gas, oil, tar or producer gas. Natural gas is the most satisfactory fuel, owing to its high calorific value and it does not contaminate the bath. It is fed directly into the working body of the furnace with out passing through the regenerator chambers. Oil is next in efficiency, but some grades are rather high in sulphur, which is absorbed by the stock in melting. Tar has been used satisfactorily, when available as a by product in the manufacture of coke. Producer gas is used extensively when near a reliable supply of coal, and is claimed to be the cheapest kind of fuel.

BASIC MATERIAL

MELTING STOCK - In the selection of stock the basic process

possesses a greater flexibility than the acid process. While it is true that there are greater latitudes in qualtity of pig and scrap, yet it must not be overlooked that the use of any kind of stock in a basic furnace cannot yield a reliable product. The ores of the Southern and South Western States produce good basic pig iron. The pig iron necessary is known as "Standard Basic", and the following table gives the limits in composition:-

Silicon	1.00	percent
Sulphur	.05	"
Phosphorus	1.00	"

STEEL SCRAP - The character of this is not considered chemically because the physical nature of it brings the composition well within working limits. It is allowable to use limited quantities of defective malleable castings, although draw bars of such material are sold as steel. Five percent of the scrap charge in malleable scrap will not materially change the melters calculations.

REFRACTORIES - The basic furnace hearth is made with magnesite,a substance classified chemically as a base, and possesses the quality, in addition to resistance to high temperatures, of being but slightly affected by a slag highly charged with lime, which would be fatal to a hearth lined with silica sand.

FLUXES - The most efficient in basic melting is ordinary limestone. Its function is to form a slag that will readily absorb the sulphur and phosphorus of the charge, and act as a vehicle for the oxidizable silicon, iron and manganese. The purer the grade the better, that is, a richness in carbonate of lime, and

freedom from silica.

MANIPULATION OF HEATS

ACID PROCESS - The order of charging the furnace will be as follows:-

First	-	Two thirds of pig iron
Second	-	Lightest sections of scrap
Third	-	Heaviest sections of scrap
Fourth	-	Remainder of pig iron

The object of charging the pig iron in two portions with the larger on the bottom, is to protect it from scorification caused by the oxide of iron formed in the melting of the scrap, which oxidizes at a faster rate than the pig iron. The pig iron on top melts first and in dripping over the scrap lowers its melting point, and in a measure protects it from undue burning or oxidization. The length of time occupied in charging depends upon the kind or size of scrap. Usually one to one and one-half hours is required.

The heat is divided into two stages. (1) The Melting; (2) The complete fusion and conversion of the materials. Little or no change in the composition takes place during the first period. The time required for melting is usually two to two and one-half hours.

Some changes occur as soon as the stock begins to melt and the slag to form. Perhaps the most pronounced change takes place by flame action on the exposed stock, it being strongly oxidizing, but not until the charge becomes entirely fused or liquid does the active part of conversion begin.

With liquifaction of the charge the flame simply becomes a vehicle of heat and under the practiced eye of the melter the thermal conditions are so maintained that the temperature of the bath is gradually increased as the conversion progresses. It is necessary that the temperature of the bath be gradually increased because of the influence of carbon. In general terms the fusing point of iron or steel depends uponthe amount of that element. The higher percentage fusing at a lower point thermometrically than the lower amounts.

Without a corresponding increase in temperature the bath of metal would become pasty, and with the bath in this condition there would be losses. In order to induce liquifaction at the first stage of conversion it is necessary to introduce carbon. This is furnished by the pig iron of the charge. Fluidity and the proper thermal conditions are then easily attained.

After the stock is melted it passes from direct flame action below a covering of slag. The existence of the slag is derived from sand carried in mechanically by the stock, the oxidization of the silicon contained in the pig iron and scrap to silica, and the oxidization of the manganese brought in by them to manganous oxide, some scorification of hearth and the oxidization of iron to ferrous oxide. Normally the slag is automatically formed, in regard to composition, throughout the progress of the heat.

Should there be an excess of iron oxide due to low silicon pig iron, there would be an excessive cutting of the hearth and it might be necessary to add sand to furnish the needed SiO , to form the adjustment of proper slag composition.

Approximately a normal slag in an acid heat consists of nearly equal parts $S\ O_2$ acid and $Fe\ O + Mn\ O$ (bases), and this composition will exist throughout the heat with a gradual increase in volume resulting from the continued oxidization of silicon and manganese and by the additions of iron ore.

The oxidization of the carbon causes a lively bubbling in the bath by the liberation of the $C\ O$ as a result of the exchange between the $Fe\ O$ of the slag and the Oxigen furnished by iron ore additions which may be expressed as follows:-

$$C + O = CO \text{ or } C + Fe\ O = Fe + CO$$

The metallic iron reduced from the slag's $Fe\ O$ and that brought in by the iron ore ($Fe_2 O_3$) is immediately absorbed by the bath. Were there no additions of ore the slag would become thick and pasty owing to the decrease of the base $Fe\ O$.

Test samples are taken regularly after melting, the fractures of which indicate the amount of carbon in them, giving guidance to the melter as to the necessary additions of ore.

In acid practice only the carbon is considered in preliminary tests, but for detailed information they may be examined for the usual elements. When in the judgment of the melter the bath needs no more iron ore and the decreasing carbon has reached a predetermined point, preparations are then made to finish the heat.

The thermal conditions being satisfactory, and the slag normal, deoxidizers and recarburizers in the shape of ferro-silicon, and ferro-manganese are then added and the heat of finished steel is ready to tap or draw off into a hot ladle.

The principal points about the manipulation of an acid heat may be given as follows:-

(1) To charge enough pig iron so that there will be ahigh enough initial carbon to ensure an easily maintained fluidity of bath. A low percentage of pig iron will mean a rapid heat but at the sacrifice of quality and a very high flame temperature. The less carbon charged the greater the chances of over oxidization.

(2) Charge as heavy sections of scrap as possible and protect it as much as possible from burning with a covering of pig iron.

(3) Watch flame conditions to guard against undue burning of stock. This point calls for a high degree of skill to maintain flame conditions and yet reach the thermal ranges necessary to melt the stock.

(4) Be Judicious in oreing heats. Too much ore is harmful, as it reduces the temperature of the bath at the very time it should be kept constant. It also introduces chemical constituents into the bath, not considered in the melters calculations.

(5) Aim for uniformity in product in a given class of work.

(6) Over anxiety for tonnage will make the scrap pile grow.

BESSEMER PROCESS

From the historical standpoint it seems that the first attempt to make steel castings by the Bessemer Process was made in Upper Silesia in the early seventies, thin steel plates for street paving purposes being cast direct from the convertor. The process did not take in Germany until 1890, when the works at Haagen bought the rights for the Walrand-Legenisel process in Germany, and in 1896 licensed Mr. Carl Rott, of Halle, to undertake the production of steel castings. The Process of Robert makes use of a side blast

while Walrand uses the ordinary bottom blast and much smaller charges than the others, thus giving it the name of the "Baby Bessemer Process". At Halle, they have a converter in which about eight hundred pound charges are blown at a time. The iron melted in a cupola near by is run directly into the converter by means of an extension of the spout. The composition of the pig iron is as follows:-

Silicon	2.3 percent
Carbon	3.5 "
Manganese	0.8 "
Phosphorus	0.7 "

Ten percent scrap from previous heats is added and the melting raito is one to twelve and one-half. Before the first charge is blown the converter is heated up with some coke burned under a light blast, then cleaned out and put into service. The process itself is interesting from the chemical standpoint, for the burning out of the silicon, Mn and C is to some extent regulated by the temperature of the bath attained. The iron from the cupola arrives at about two thousand three hundred degrees Fahrenheit. Neither Carbon or Manganese will furnish fuel for this high temperature, but Silicon does, every percent of Silicon thus burned being equivalent to a rise in temperature in the bath of over five hundred degrees Fahrenheit. As the temperature gradually rises the point is reached, two thousand five hundred fifty degrees Fahrenheit, at which carbon will combine with oxygen before the silicon can get it, and hence the silicon will not go quite so fast while the carbon is reduced very rapidly. The German, English, and Swedish adaptations of the Bessemer process are based upon this

phenomenon. Thus the German pig iron being fairly high in silicon, there is frequently a very high temperature in the converter. The burning out of Silicon practically ceases at two thousand five hundred degrees Fahrenheit. The carbon now burns out leaving about 0.3 percent silicon in the bath. Ferro-manganese being now added, the after blow brings the bath to the proper composition, and temperature for casting. The German process of Bessemerizing is therefore characterized by the high initial temperature and the recarburization.

The English process deals with iron much higher in silicon and manganese. It is possible to blow with a temperature much lower than the German. Nearly all the silicon and manganese is burned out in the first six minutes. The carbon then goes and with it the rest of the silicon, for the burning of the carbon tends to lower the temperature of the bath slightly. In twelve minutes the 3.75 to 4 percent of carbon is gone and Spiegel is added to get the proper composition.

In the Swedish process the irons are so low in silicon that it must come from the cupola very hot. The burning of the silicon is just sufficient to reach the point at which the carbon can go, and not enough to allow recarburization. It is, therefore, necessary to stop the process at the exact carbon content and cast at once.

In the application of the Bessemer process for small steel castings it is necessary to get a very high casting temperature, and hence Walrand adds five to ten percent of melted ferro-silicon to the bath after the carbon is gone. An after blow lasting about one minute is given, and then the final 0.66 percent of ferro-man-

ganese is added. The addition of the ferro-silicon and the after blow results in a very high casting temperature. The addition of the ferro-manganese results in the boiling up of the mass of steel, which subsides as soon as the reaction has taken place. Right at this point will be found the success or failure of the blow, there being but little time before the cast must be made, it is difficult to get rid of the gases completely. A test is made as soon as the bath is quiet, by pouring some of the steel into a small ingot mould. If the metal solidifies and sinks it is in the proper condition. If it boils over there is too much gas left in it, and more silicon, manganese or aluminum must be added. As this is often too late the result is often a miss cast, which goes to profit and loss.

TROPENAS PROCESS FOR MAKING STEEL,-FORM OF BESSEMER - The first Tropenas converter used was of a capacity of about eight hundred pounds was erected in 1891-2 in the works Edgar Allen & Company, Ltd., Sheffield, England. The trials there made were so satisfactory that after a few weeks the above named firm decided to build a two-ton converter, and since then two others have been erected with which all its steel castings are made. The output of the works at the present is over nine thousand tons annually.

In all of the plants now in operation by the Tropenas process, the manufacture of general steel castings for machinery and electrical purposes has been carried on with great success, fulfilling all the physical and chemical requirements. Ingots have been made as well as anvils, hammers and similar articles. The ultimate strength is sixty-five thousand to seventy-three thousand pounds

per square inch, and the elastic limit is thirty thousand to thirty-eight thousand pounds per square inch. The elongation in two inches, twenty-seven to thirty-seven percent. and the reduction of area forty-five to fifty-seven percent,

Dynamo Magnet steel of extreme purity and permeability can be made with absolute regularity and tests made both in Europe and in this country show that the product has a permeability not equalled by steel made with any other process.

Large and small castings are made at will. It is especially adapted to small and medium castings, which are made with great facility, sound, free from blow holes and of a high physical quality. The process is also well adapted to large castings, weighing up to ten tons. This can be done by running to two-ton converters alternately and collecting the steel after each operation in a ladle until the desired amount is obtained. This is made possible owing to the great heat and consequent fluidity of the metal. It has been found in past years that even with obsolete types of cranes and foundry appliances five or six blows could be collected this way, and afterwards poured over the lip of the ladle, leaving no skull. Castings up to five tons can be made with one two-ton converter in the same way.

The Tropenas process consists of a special converter in which iron, melted in a cupola beforehand, is converted into steel. This vessel like all other converters is a sheet steel shell lined with silica brick or ganister. The shell is fitted with two hollow trunions carried on pedestals so that the apparatus may be tilted according to the requirements of the operation, i.e., charging the molten iron, pouring the steel, etc. The interior of the converter

is so designed that the metallic bath has a much greater depth than in all other pneumatic processes. The blast enters the converter from the pressure blower through the trunions, feeding the wind boxes and tuyeres, which direct the air over the metallic bath.

Before commencing operations the converter is heated by means of coke or crude oil, afterwards no fuel is needed in the converter, as it is supplied by the metalloids in the iron which are to be eliminated.

The pig iron and steel scrap having been melted in a cupola, or other furnace, is run into the converter; the position of the converter relative to the level of the metal is then adjusted so as to have the proper conditions for blowing. The blast is started and at a certain period of the operation a supplementary blast is introduced at will by means of the auxiliary tuyeres. This completes the combustion of the escaping gases, raising the temperature of the bath by radiation. At the endof the operation a bath of very fluid and soft metal is the result and recarburization is made in the vessel or in the ladle as in other processes. By varying the final additions steel of any desired hardness or quality may be produced exactly.

The blast pressure required varies between three and four pounds per square inch, according to the kind of pig iron treated. The blast can be produced by a blowing engine or a positive pressure rotary blower.

By what has been said, it is apparent that the characteristic features of the Tropenas process are the following:-

(1) Low pressure blast, afforded by auxiliary tuyeres, always above the survace of the metal.

(2) Special disposition of the tuyeres in the horizontal plane so that the jets of air will enter into the converter above the bath and will not impart to it any gyratory or tumultuous motion whatever.

(3) Great depths of the metallic bath so as to avoid stirring and churning during the operation. The result is that the steel contains very little occluded gases and, therefore, pours quietly into the molds, producing castings free from blow holes.

(4) Arrangement above the "fining tuyeres" and independent of the latter, of auxiliary or "combustion tuyeres", so as to burn the combustible gases which escape from the bath, and which in all other pneumatic processes pass unconsumed up the chimney. The combustion of these gases increase the temperature of the bath very considerably. This mades the subsequent manipulation of the steel in pouring, etc., much easier and more satisfactory. As many as one hundred fifty moulds have been poured from a heat of about thirty-five hundred pounds, with bull ladles holding about one hundred twenty-five pounds each.

By the use of auxiliary tuyeres the carbonic oxide arising from the bath is transformed into carbonic acid gas. The loss of metal during the operation, including cupola and converter is about seventeen percent, It varies one to two percent according to the kind of material used and the ability of the melters.

The pig iron used for the production of castings by this process analyzes as follows:

Silicon		2. to 4.	percent
Manganese		.5 " 1.25	"
Carbon		3.0 " 4.5	"
Sulphur	up to	.06	"
Phosphorus	" "	.07	"

The sands required for making moulds are the same as used in steel foundries employing other processes, and the moulds are dried or not, according to the kind of casting to be made.

The steel as it comes from the sand is perfectly soft and malleable.

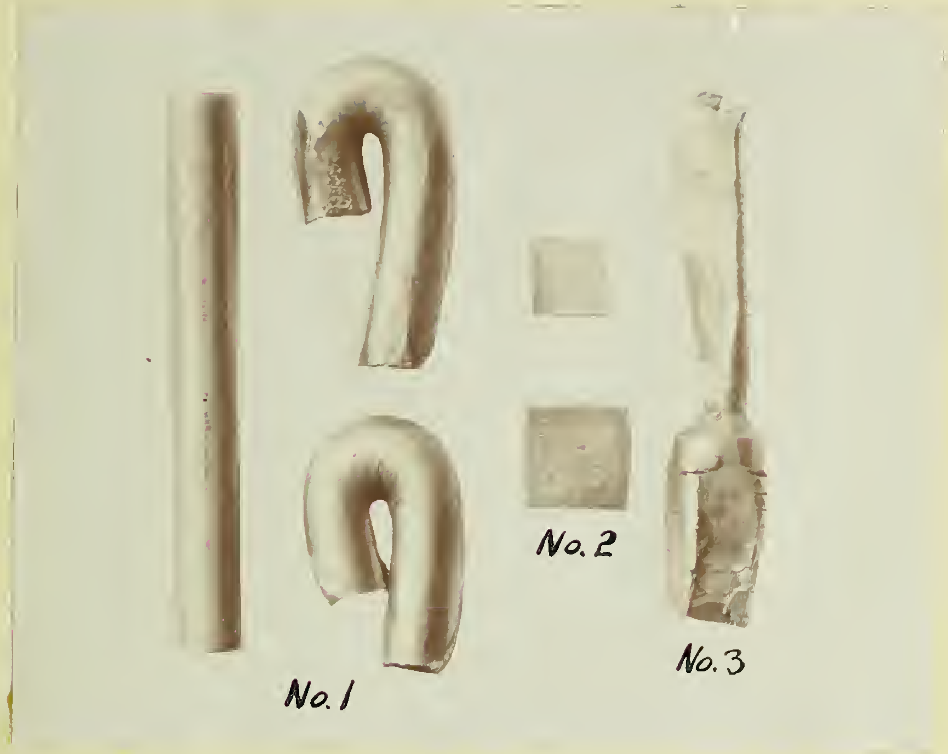
Each operation in the converter lasts from twelve to twenty minutes. The time required for pouring the steel into the ladles and preparing the converter for another blow varies according to the style of castings made. One of the foundries using this process stated that they had made eleven blows in an average of twenty-five and one-half minutes per blow with one two-ton converter.

It is claimed that there is no process that produces steel so suitable for electrical purposes as this one, dynamo and electrical castings being made very satisfactorily and with great regularity.

This process, unlike the Open Hearth, permits intermittent operations,as the heating of the converter is cheaply accomplished. According to the demands of the market the foundryman can work his converter continuously, or he may discontinue until he has again gathered a sufficient number of molds to warrant him to fire again, exactly in the same conditions as melting in a cupola.

REPORT OF CHEMICAL AND PHYSICAL TESTS OF STEEL CASTINGS.

No.	CHEMICAL ANALYSIS. CARB.	PHOS.	SUL.	MANG.	SIL.	ORIGINAL AREA.	REDUCED AREA.	MAX. LOAD.	ULT. STRENGTH	YIELD POINT	ELASTIC LIMIT	ELONG. IN 2"	PER CENT ELONG.	PER CENT REDUCTION	FRACTURE.
1	.42	.030	.025	.47	.241	.202	.152	14680	72670	×	×	.453	22.60	24.2	Granular
2	.42	.030	.025	.47	.241	.199	.150	14600	72810	×	×	.420	21.00	24.6	Granular
3	.39	.039	.031	.50	.262	.197	.125	13970	70910	7100	36040	.625	31.25	36.5	Silky
4	.39	.039	.031	.50	.262	.197	.116	13520	68630	×	×	.593	2965	41.1	Silky
5	.39	.039	.031	.50	.262	.197	.125	13770	69890	6500	32990	.580	29.00	36.5	Silky
6	.39	.039	.031	.50	.262	.192	.132	13060	68020	6500	33850	.460	23.00	31.2	Silky
7	.44	.027	.036	.60	.256	.199	.136	13700	68340	6000	30150	.530	26.50	31.6	Silky
8	.44	.027	.036	.60	.256	.196	.165	13400	68360	×	×	.340	17.00	15.8	Granular
9	.30	.038	.025	.72	.232	.199	.116	14050	70650	6800	34170	.580	29.00	49.5	Silky
10	.30	.038	.025	.72	.232	.200	.119	14000	70000	7000	35000	.550	27.50	40.5	Silky
11	.35	.037	.025	.46	.271	.201	.115	13780	68550	×	×	.570	28.00	42.1	Silky
12	.35	.037	.025	.46	.271	.197	.125	13400	72990	×	×	.530	26.50	36.7	Silky
13	.35	.037	.025	.46	.271	.199	.113	12710	66080	×	×	.620	31.00	43.8	Silky
14	.34	.033	.030	.64	.248	.197	.121	13360	67810	7800	39590	.590	29.50	38.5	Silky
15	.34	.033	.030	.64	.248	.196	.118	13400	68360	×	×	.550	27.50	39.7	Silky
16	.34	.033	.030	.64	.248	.191	.119	13920	72820	8280	43350	.540	27.00	37.6	Silky
17	.38	.038	.022	.63	.198	.191	.126	13040	68270	8000	41880	.570	28.50	34.0	Silky
18	.38	.038	.022	.63	.198	.198	.130	13140	66360	9210	46510	.560	28.00	34.15	Silky
19	.38	.038	.022	.63	.198	.194	.128	14910	76870	8580	44220	.470	23.50	34.00	Silky
20	.38	.038	.022	.63	.198	.195	.142	15430	79120	7722	40100	.450	22.50	27.1	Silky
21	.44	.027	.036	.60	.256	.199	.130	13640	68540	7100	36180	.530	26.50	34.6	Silky
22	.44	.027	.036	.60	.256	.191	.131	13080	68480	8430	44130	.520	26.00	31.2	Silky
23	.40	.024	.024	.74	.257	.195	.171	10100	59790	11580	58780	.080	4.00	12.3	Crystalline
24	.47	.020	.019	.72	.243	.197	.161	12250	62180	×	×	.140	7.00	18.2	Silky
25	.51	.027	.027	.83	.377	.194	.186	15240	78350	14000	71790	.080	4.00	4.1	Crystalline
26	.46	.023	.022	.85	.369	.195	.126	17620	90350			.430	21.50	35.3	Silky
27	.48	.015	.009	.73	.331	.191	.190	12560	65750	16000	83760	.010	0.50	0.52	Crystalline
28	.54	.019	.012	.75	.328	.191	.184	19700	103140			.080	4.00	3.66	Granular
29	.49	.022	.015	.59	.285	.195	.194	11310	58000	×	×	.020	1.00	0.51	Crystalline
30	.44	.016	.016	.61	.539	.192	.170	20000	104160	×	×	.160	8.00	11.40	Silky.



SPECIMEN NO. 1 of photograph shows effect of cold bend test. The bars used in this test were one-half inch (1/2") in diameter.

SPECIMEN NO.2 shows the effects of compression. One-half inch cube used. Elastic Limit was 128320 lbs. Cubes mashed down without fracture.

SPECIMEN NO. 3 shows a piece that was hammered cold. Rectangular end was three-quarter inch (3/4") in diameter before hammering, and was threaded. Piece did not fracture.

- PURIFIER OF STEEL CASTINGS -

About 1901, the Krupp Company obtained a German invention for the removal of oxygen from molten metals, such as steel, ingot iron, nickel steel, etc. The oxygen combines with carbon to form carbonic oxide, this combination takes place slowly; even during the setting of the metal, so that blow holes are liable to be formed. The invention consists in a discovery that oxygen can be removed and the formation of an impurity in the iron or steel prevented by adding to the metal while in a molten condition, either during casting or before, instead of aluminum alone or its alloy with iron, an alloy consisting of one or more metals such as aluminum of manganese, having a greater chemical affinity for oxygen than the metals to be cast, and one or more electro-negative, non-metallic elements or metalloids, such as silicon or baron. The elements of this alloy are converted by taking up the oxygen from the casting into single, double, or multiple silicates, borates, etc., which produce a readily fusible slag. This rises quickly to the surface and leaves the casting pure and free from blow holes.

In the treatment of steel,aluminum and manganese are employed for this purpose. If the manganese be omitted from the alloy it is still probable that a double salt will be formed. However, the presence of manganese positively insures a fusible slag.

- EFFECT ON CASTING -

THE ADDITION OF SILICON IN THE BASIC PROCESS - Perhaps no more troublesome features have arisen among manufacturers of steel castings who are using the basic process than the control of the

silicon in the furnace additions just previous to tapping.

From the nature of the method whereby the phosphorus is all or nearly all removed from the metal by the lime flux employed, the compound thus formed between the phosphorus and calcium of the flux is very easily dissociated, leaving the phosphorus in a liberated state, which is quickly re-absorbed by the steel in the bath. This breaking up of the chemical compound is usually caused by the addition of silicon or silicates, which form silicates of calcium and set free the phosphorus.

It often happens in analyzing a cast of basic steel that a percentage of phosphorus is found which in some is so great as to preclude any possible uses of the castings with safety.

Among works employing the basic process and where experiments and tests along this line have been made, it has been found that the last furnace test sent to the laboratory previous to tapping, has shown less than .005 percent phosphorus, and the castings poured would sometimes reach as high as .15percent phosphorus.

This return of phosphorus to the metal may be attributed to three causes. The first of which is the injudicious use of ore when the carbon is already nearly low enough to conform the requirements. Melters as a rule often try to hasten a heat at the finish for no other reason than their personal desire to have an early tap. To do this they lower the carbon rapidly by the use of iron ore; overcharging the metal with oxygen and oxides, which eagerly unite with the silicon subsequently added, thus forming new silicates to react detrimentally upon the slag. The metal not only picks up more phosphorus, but is apt to be "wild" in the moulds,

caused by the insufficient amount of silicon present to quiet the metal. An increase of aluminum or manganese, as before stated, would to a certain extent act beneficially, but if the use of ore is prohibited toward the final time of refining much more satisfactory metal is produced.

The second cause, though not of common occurrence, is the entrance of silicates into the bath from molten silica brick running down from the parts and roof of the furnace.

The third cause has been the improper addition of silicon, causing harmful action by the slag on the metal.

The method usually pursued is to allow ferro-silicon, or silico-spiegel additions to melt in the bath after being first preheated to redness or below that temperature. In this way a considerable portion of the silicon is lost and taken up by the slag, giving a higher phosphorus metal with a much lower silicon content than would be shown by calculations of the exact percentage, based on the analysis of the material used in the addition. In the most carefully conducted heats this loss of silicon is apalling, and while perhaps this is given little consideration by the management it is really a matter of dollars.

STRENGTH AS AFFECTED BY TEMPERATURE - Experiments have been made by Mr. C. Bach to determine the relation of mechanical strength of steel castings to temperature. It is shown that the average tensile strengths increase up to about three hundred degrees Centigrade, time of loading not having any appreciable influence. For higher temperatures, on the other hand, the mean tensile strengths are found to decrease when loads are applied for half-an-hour,

and still more when the loading continues for eight to twelve hours. The average breaking strengths are found to decrease very considerably in some cases with a temperature range of twenty to two hundred degrees Centigrade, but above that point the average breaking strength increases again up to five hundred degrees centigrade. The average reduction of area decreases up to three hundred degrees Centigrade, but at higher temperatures there is again an increase, the results being influenced by the prolongation of the load. While steel castings give very satisfactory and uniform tensile tests at ordinary temperatures, may present but little tenacity and uniformity at higher temperatures.

MOLDING MATERIALS - Since all steel castings are poured at higher ranges of temperature than gray iron or malleable castings it is essential that the sands and clay (binders) be as regractory as possible. Pure silica is the most desirable - the more nearly pure the better. The following is an analysis of a steel moulding sand:-

Silica	98.5	percent
Alumina	1.40	"
Iron Oxide	.06	"
Lime	.20	"
Magnesia	.16	"
Combined Water	.14	"
Alkalies	.25	"

It must be of such a nature or structure physically that the heated gases in the mould when displaced by liquid steel will have a free passage outwardly. It is preferable that the grains be

sharp and irregular rather than rounded as would be the case with sand subjected at some time to the action of water. The color is often white or slightly yellow. Its color is not necessarily a guide as to its qualities, but it is often an indication.

FIRE CLAY - Pure silica sands have no binding qualities and varying amounts of clay are mixed with it to give the sand a needed bond and substantiality to the mould prepared to receive the hot steel. The clay must also be refractory and possess a maximum degree of plasticity. Low grade sands and clays would fuse at the temperature of liquid steel and cause the casting to be of an irregular rough surface. An attempt to economize in the sand pile is apt to spoil one's reputation for clean looking castings. It is not always reliable to have resource to chemical tests on refractories or moulding materials, since actual practice will affirm the desirable qualities in them.

The following is the composition of a typical fire clay:

Silica	60 - 66	percent
Aluminum	20 - 25	"
Iron Oxide	2	"
Lime	1	"
Magnesia	1	"
Alkalies	2	"
Combined Water	7.5 - 10.5	"

The value of the fire clay depends largely upon a low content of alkalies and a freedom from carbonates of lime. Oxide of Iron has a strong fluxing effect, but its presence below three percent is harmless.

CORE COMPOUNDS - Any reliable proprietary article will answer and the list will include molasses water, resin, flour, linseed oil, etc., all of which are well known.

The best sand to be used in making steel castings in green sand is pure sharp silica sand with just enough clay to make it plastic.

Such a moulding sand is sometimes found in nature, but when it cannot be obtained as a natural product it may be made by mixing, say, two parts of sharp silica sand with one part of Kaolin. Other mixtures may be made providing the resulting material is refractory, plastic, and open enough to allow the gases to escape.

Hard steel castings, that is, those with a high carbon content can be made in a mould that is less refractory than that required for soft steel castings.

The finished mould is dusted, or sprinkled over with ground refractory fire clay, ground or powdered old crucibles, or with powdered quartz.

The gates on a steel casting should be placed in such a manner that liquid metal is fed to any place separated from another gate by intervening thin parts. This is necessary on account of the fact that thin parts always set more quickly than the heavy parts, and hence the steel has to be fed to these parts through specially prepared gates. If no feeders are provided for these isolated thick parts they will contain blow holes.

INFLUENCE OF CASTING TEMPERATURES - The occasionally erratic behavior of castings of known composition and suitable treatment is familiar. Steel castings of identical composition and an-

nealed under similar conditions, at times show a wide variation in their mechanical properties. Further, with equal properties, as shown by the tensile test, steel castings may, under certain conditions, vary in their resistance to working stresses, and in extreme cases fracture may occur at comparatively low stresses.

The present state of foundry practice is such that all conditions, save one, may by the exercise of suitable care, be held in good control. That one condition is the temperature of the metal as it enters the mould.

There is no danger of mild crucible steel being poured at too high a temperature, however, there is a strong possibility of its being cast too cold. A peculiar feature of mild crucible steels being poured at "fair" and "cold" heats lies in the fact that generally their tensile properties are very similar, if not identical; the actual properties of these steels are, however, anything but similar, and from one crucible two castings may be obtained, one of which may be dangerously brittle.

In some very elaborate tests Mr. Percy Longmur gives the following: "A casting showing a tenacity of twenty-eight tons per square inch and an elongation of twenty-six percent fractured after forty-one reversals. High grade iron as cast and annealed fractured on seventy-two and one hundred ninety-eight reversals respectively. As an extreme illustration, a casting of thirty-eight tons maximum stress and four percent elongation fractured on four reversals, a similar casting poured at a slightly lower temperature broke on eight reversals. After annealing, these results were raised to twenty-six and one hundred two reversals respectively."

An important requisite for sound castings is a large sink head. These feed the casting during contraction, and must be heavy enough to act as an applied pressure on the casting. About forty percent of the metal tapped from the furnace is used in these sink heads.

ANNEALING - The familiar quotation "true as steel" has on many occasions recieved a rude shock, leaving a doubt in the minds of its users as to the fitness of the phrase. Mention may be made of the United States Government going back to the old fashioned wrought iron anchors for its ironclads in view of the treacherous and mysterious failures of the most approved type of cast steel kedge anchors. Other instances could be introduced along similar lines proving that steel may be ideal in its chemical composition following the most rigid specifications of any given class, and yet with out any warning and possibly at a most critical time may fail in service or manifest an excessive degree of brittleness. The natural question is what causes this brittleness. With abnormal chemical composition the answer might be easy, but when normal chemically the explanation is much more difficult. The question has received the attention of many worthy and patient investigators; each advancing elaborate hypotheses and theories with some degree of truth; but it remained for the microscope to give the true explanation leading up to the cause of brittleness in steel. The brittleness in steel castings is due to a degree of crystallization as a result of imperfect heat treatment. This being true, as proved by tests and experiments, the nearer cast steel approaches a non-crystalline or distinctly amorphous structure, the less will

be the degree of brittleness, or conversely the greater the degree of toughness. It can be shown that it is possible to have two pieces of steel identical in composition, yet possessing contrasting physical properties. To the uninitiated, this may seem very mysterious, but when the effect of heat treatment is understood the explanation is simplified by the comparative study of the structure of the pieces as revealed by the microscope. Great credit is due to Sanneur and other eminent microscopists, who by their labors have given the world knowledge of much moment to the industrial side of the metallurgy of steel.

Before advancing arguments in support of the necessity of annealing all ordinary steel castings, it may be well to mention briefly the effect of heat upon the micro-structure of cast steel and its physical properties, since the relation between the two is distinct. The term "annealing" herein used is not meant that long continued heating at a white heat generally accepted as annealing, which in reality is mere soaking. Properly speaking, annealing is that process of heat treatment of cast steel by which crystallization or brittleness is removed, conferring upon the metal its best possible physical condition, the degree of heat being governed by the carbon content, and the length of time by the size of the piece. If a piece of steel be allowed to cool (not quenched) from the casting temperature, its fracture will be more or less crystalline, and the micro-structure correspondingly coarse, depending upon the initial temperature and the rate of cooling. Such steel possesses fairly good tensile strength, low elongation, and comparatively no resistance to impact. Upon reheating to a suit-

able temperature the changes in the crystallization, if fractured, are very marked, the large ones of the original piece having disappeared, being replaced by a fine grain. The micro-structure will be found also very fine with the carbon compound evenly distributed throughout the mass. Such steel will be slightly lower in tensile strength, will be much improved in reduction of area and elongation, and all brittleness being removed, can be hammered cold, and bend flat upon itself without fracture. This last named test gives more information of the physical condition as a result of careful heat treatment than can be gained by the steady pull of a testing machine; even with considerable elongation, usually regarded as an evidence of toughness, since it is known that steel can elongate and still have little resistance to shock. There is no part of the manufacture of steel castings that receives more abuse than the reheating, and it is not to be wondered that some claim that such treatment is unnecessary; but when it is understood that the best possible physical properties of normal steel for a given class can only be acquired by careful heat treatment, there can be no doubt that any manufacturer of steel castings with the aim to reach the best results will be willing to give the problem serious attention.

Given a normal chemical composition, the physical properties of cast steel regarding resistance to all strains, then, are solely a function of heat treatment; so to produce the desired and most important quality. namely, resistance to impact, the temperature of annealing is confined necessarily to certain limits; otherwise, the attempt is defeated, since a high heating produces crystallization and its equivalent brittleness; or in case of too

low a heating the original coarsely crystalline structure conferred by the casting temperature will not be removed. Herein lies the secret of tough steel.

- CONCLUSION -

In conclusion, with the deserving attention to both the chemical composition and subsequent heat treatment, steel castings can be made with such properties physically that will insure results in service to an extent that when not strained beyond the elastic limit of the metal, they will have a life that will be practically indefinite.

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